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Bioengineering as a Tool for Restoring Ecological Integrity to the Carson River

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PURPOSE: This technical note describes a case study involving the following: (a) use of bioengineering (a combination of vegetation and engineered structures and materials) and rock structures to restore an eroded bank of the Carson River, Nevada, and (b) restoration of ecological amenities that existed prior to disturbances by man and a major flood event.

BACKGROUND AND OBJECTIVES: A 100-year flood event in January 1997 caused considerable erosion and damage to the banks and riparian habitat of the Carson River. As a result, adjacent landowners sought erosion protection and habitat improvement under various federal relief programs, such as the Emergency Watershed Protection Act and the Wildlife Habitat Improvement Program. Several federal, state, county, and local agencies acknowledged below formed an informal partnership to address the erosion and resulting habitat damage/loss caused by this flood.

This partnership decided that one damaged bendway with banks that had been cut back 15 or more ft (4.5 m) by the flood would serve as a site to focus a classroom workshop and follow-up demonstration of various erosion control and habitat improvement treatments (Figure 1). The demonstration site was next to residences whose back yards or fields had been eroded along with adjacent riparian vegetation (Figure 2). The flood caused this erosion, but the effects were exacerbated by management activities, such as mowing immediately adjacent to the streambank. The lack of vegetation and storm-caused erosion contributed to a lack of ecological amenities in the riparian zone, e.g., lack of habitat, increased sediment loads, increased water temperatures, and other water quality parameters.

New erosion control techniques, such as bioengineering, were sought to address the problem and to show that such techniques could be permitted under Section 404 of the Clean Water Act using a general permit. Historical treatments using conventional engineering treatments (i.e., revetted riprap) were considered by some individuals and agencies within the partnership as having minimal environmental value and better, more environmentally acceptable treatments were sought.

The partnership of agencies conducted a workshop and demonstration (hereafter referred to as a workshop) in November 1998 that was attended by both the general public and various personnel within those agencies. The resource professionals and instructors hosting and presenting the workshop conducted a reconnaissance visit prior to the workshop to characterize the site conditions, identify the demonstration reach, and select treatments. It was determined that various hard structures, such as rock barbs (Figure 3) and dikes would be needed along with bioengineering

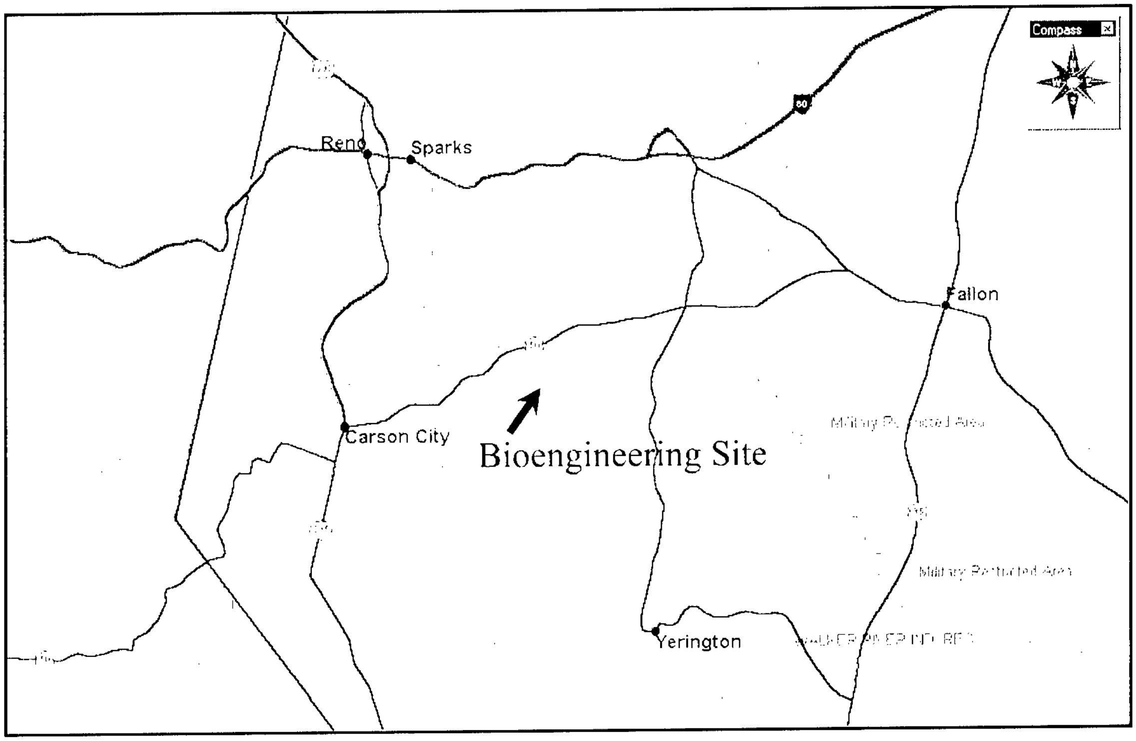

Figure 1. Location of bioengineering site on Carson River northeast of Carson City, NV

Figure 2. Carson River bendway site in background (left side of photo) prior to any bioengineering treatments

Figure 3. Bioengineering treatments between rock barbs; the barbs are used to deflect currents away from bank (move the thalweg)

treatments because of the stream's potential flooding duration and frequency in the spring and the magnitude of concomitant current velocities and shear forces. Such hard structures would deflect currents away from the bank, move the thalweg, and prevent toe scour and undercutting. The combination of hard structures and bioengineering would also lead to sediment deposition behind the structures, thus recovering some of the receded bank.

DEMONSTRATION TREATMENTS: Five stream barbs, such as those shown in Figure 3, along with rock refusals (rock trenches buried into the bank), rock toe protection, and a peaked stone (trapezoidal-shaped) dike running parallel to the bank were selected as hard structures to be used in conjunction with the bioengineering treatments. All of these covered a 600-ft (182.88-m) reach of bendway and were used to illustrate to workshop attendees an array of treatments. The treatments selected were adapted from those presented in previously successful bioengineering efforts conducted on other stream systems (Allen and Leech 1997, Bentrup and Hoag 1998).

The stream barbs were pointed upstream; specifically, their center line was positioned 30 to 45 deg from a line tangent to the streambank (Figure 4). Their slope was 10H:1V from the top to the toe and they had at least an 8-ft (2.4-m) rock refusal root extending into the bank. Note that the toe of the barb was keyed into the bed of the river for scour protection. Side slopes were 2H:1V. Such a configuration allowed water to be deflected away from the eroded bank at all water levels and also allowed sediment to accumulate behind the barbs.

Five bioengineering treatments were used either between the five barbs or landward of a peaked stone dike (Table 1). Three of these treatments consisted of live, but dormant cuttings of coyote willow (*Salix exigua*) arranged in various configurations, such as vertical bundles (Figure 5) with a juniper tree revetment as toe protection. The other two treatments consisted of brush mattresses, one of which had a rock toe and one that did not. A fourth treatment consisted of live willow clumps of coyote willow with roots attached and buried landward of a juniper tree revetment that served as toe

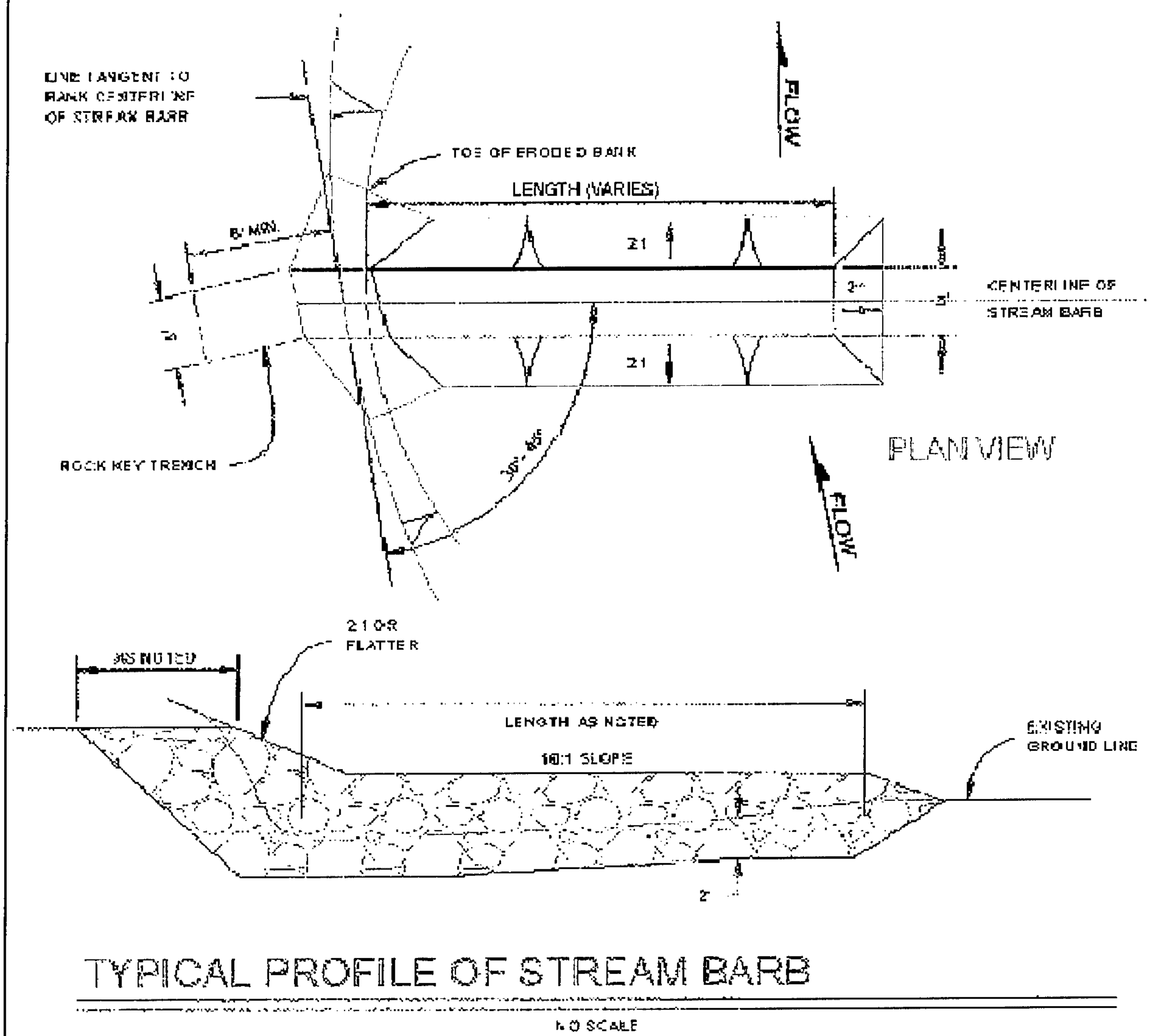

Figure 4. Plan and profile views of stream barb

protection between two of the barbs (Figure 6). The fifth bioengineering treatment, called brush layering, was installed using dormant cuttings of willow along the inside face of a peaked stone dike (Figure 6). The area was backfilled after installation and provided immediate overhanging shade and cover of the stream to promote aquatic habitat.

Table 1
Bioengineering Treatments

Treatment[1]	Description
1	Brush mattress with fascine, but without rock toe
2	Vertical willow bundles on 6-ft centers with cedar tree revetment at toe and erosion control fabric on upper bank
3	48 live willow clumps with cedar tree revetment at toe and erosion control fabric on upper bank
4	Brush mattress without fascine, but with rock toe
5	Brush layering in combination with a peaked stone dike and erosion control fabric on upper bank

[1] Treatments listed in order of occurrence from upstream end of demonstration to downstream end.

Figure 5. Installation of vertical willow bundles landward of juniper tree revetment; the tree revetment served as toe protection between two barbs and promoted sediment deposition

Figure 6. Three bioengineering treatments: (a) live willow clumps with a juniper tree revetment (foreground); (b) workshop attendees installing brush mattress with rock toe protection (middle of photo); (c) brush layering over peaked stone dike (far right of photo). Erosion control fabric with seeded riparian grasses appears on upper bank on left side of photo

Three of the treatment areas were planted with a mix of native riparian grasses and covered with a commercially produced erosion control fabric (ECF) composed of coconut husk fibers (Figure 6).

MONITORING: Surveyed cross sections at six locations along the treated stream reach were established before treatment and monitored twice after treatment for 2 years, August of 1999 and 2000, to determine changes in channel morphology. The six cross sections are respectively co-located with the hard structures and various bioengineering treatments between and among the structures (barbs and peaked-stone dike).

Nine fixed vegetation transects of varied lengths (13 to 100 ft or 4 to 33.3 m, depending on length of bioengineering treatment) with two to four 1-m^2 sample plots (quadrats) per transect were established so that each bioengineering treatment was traversed and evaluated. Vegetative cover and regeneration could be estimated using evenly spaced quadrats along each transect. Information collected consisted of the number of willow sprouts and number of cottonwood seedlings and an ocular estimate of percent living vegetation (forbs, grass, and woody) compared to percent bare ground and percent dead vegetative cover. The willow clump treatment was evaluated based on the percent of the willow clumps regenerating. Just as the surveyed cross sections of the channel, this vegetative monitoring was also performed for 2 years, in August of 1999 and 2000.

It is noteworthy that during the monitoring period between project construction in November 1998 and August 2000, an estimated 5-year flood event of about 4000 cfs (113 cms) occurred in May 1999; normal spring runoff is about 2500 cfs (70.8 cms) for this reach of river. This was fortuitous

because the higher runoff inundated the bioengineering treatments, thus giving them a good test of flood duration and shear-stress tolerance. The flood also caused anticipated sediment buildup. This is discussed below.

Surveyed Cross Sections

Sediment deposition. Cross-sectional surveys of the site before construction (1998) and 9 months following construction (1999) showed that 430 yd^3 (12.2 m^3) of sediment was deposited in the treated sections between the first and fifth rock barbs along the bendway. This sediment was largely a result of the 1999 flood. According to survey data collected in 2000, the amount of sediment previously deposited in 1999 was holding constant. This stable amount was due, in part, to the lack of high flows in the spring of 2000 to move the sediment and the configuration of the stream barbs. The only notable increase in sediment was observed between the first and second barbs upstream.

Channel morphology. The cross-sectional survey information taken between 1998 and 2000 illustrates that with one exception, the thalweg moved away from the bendway bank and that sediment accumulated between the barbs as designed (Figures A1 to A3, Appendix A). There has been 1 ft of scour in the thalweg at the most downstream station (1 + 10) and there is some evidence that scour and the change in depth of the thalweg have removed a portion of the sediment that accumulated during the prior year. At this same station, the right bank has changed in contour. The gravel bar associated with the right bank has lost material as expected and now approximates pre-project conditions. The remaining cross sections appear to be relatively stable, with only insignificant changes to the channel morphology.

Vegetation. The nine fixed transects for monitoring the success of the bioengineering treatments indicated there was an average cover increase from 74 to 81 percent for all treatments between 1999 and 2000. After 2 years, the highest vegetative cover was associated with the brush mattress that had the rock toe and the brush layering associated with the peaked stone dike. The highest number of willow sprouts after 2 years was associated with the vertical willow bundles above the juniper tree revetment. All treatments containing willow displayed an acceptable amount of vegetative establishment and cover (Figure 7). The ECF above three of the willow treatments did not perform as expected because of a lack of precipitation and irrigation. The planted grass seed did not germinate substantially.

The second year ocular inspection of the willow clump bioengineering treatment revealed 22 out of 48 (46 percent) of the willow clumps regenerating and spreading, while the other 26 (54 percent) willow clumps were buried by large amounts of deposited sediment between the barbs and within the treatment area.

Figure 7. View upriver in August 2000, 21 months after installation of bioengineering treatments; the peaked stone dike with brush layering is shown in foreground

COSTS: Total costs for this project were $61,810.55 ($103.00/lin ft; $340.00/lin m). Cash expenses were costs for construction items and materials. In-kind expenses amounted to $16,184 ($27/lin ft; $89/lin m) and were for plant materials, labor, and equipment. In-kind expenses comprised 26.5 percent of the total cost of this project. The neighboring landowners and the local river management group provided the in-kind services. Bioengineering treatments alone (without the rock structures) cost from $35 to $50/lin ft ($115 to $165/lin m).

DISCUSSION: The construction of this project and its monitoring over the last 2 years have resulted in a number of considerations for future projects of this type:

- When planning and designing a stream restoration project, use an interdisciplinary team of professionals, e.g., engineers, ecologists, landscape architects, geologists, hydrologists, and others, that can address such things as fluvial geomorphology, hydraulics, engineered designs, soils, plants, wildlife habitat, water quality, etc. Using several disciplines may be a challenge, but well worth the effort in terms of achieving a successfully permitted project and ultimately achieving an ecologically sound project that functions properly.

- The use and benefits of ECF can be negated if the upper bank is not irrigated, particularly in an arid-semiarid climate like that of the Carson River, Nevada, where annual precipitation is in the range of 8 to 10 in. Seeds covered by the ECF will not germinate without adequate moisture and as a result, the soil is not held by what would have been the binding roots of the grasses. The authors feel that where irrigation is impractical, such as remote areas, vertical willow bundles

could be used in lieu of the ECF if the bundles can be placed so as to cover the entire slope of the bank.

- The design and installation of stream barbs proved to be a very effective way to protect streambanks that are subject to excessive shear forces and resultant scour from impinging flows. The design allowed currents to be deflected away from the bank regardless of varying water levels. The barbs allowed the system to create calm water pockets, deposit sediment, and led to resultant vegetative cover from bioengineering treatments. The barbs (with accumulated sediment between them) and the movement of the thalweg will contribute to regaining land and habitat.

- The project benefited from construction in two phases: (a) shaping the banks and placement of stream barbs and dikes during low-flow periods, such as August through October, and (b) construction and placement of bioengineering treatments after the vegetation to be planted has gone dormant. This two-phased approach improves equipment access for shaving the banks and placing rock, improves the ease of operation, and reduces cost.

- Over half of the live willow clumps on this project were covered by sediment and did not regenerate because the clump stems were cut too short. Had they been about twice as long (36 in. or 92 cm versus 18 in. or 46 cm), they probably would have had stems above the sediment and would have lived.

- The juniper tree revetment was an added bonus for collecting and holding sediment between the stream barbs; over time, this will have the effect of regaining land lost.

- The use of a peaked stone dike should be considered in areas where reshaping or laying the slopes back would destroy some valuable natural resource or where there are existing land-use constraints. This was the case on this bendway where a significant riparian cottonwood grove existed that was co-located with a horse corral. Laying the bank back would have destroyed this habitat resource and would also have destroyed an existing fence to a corral.

- Finally, a monitoring program should be planned before the project is built and be conducted for at least 2 years after installation and preferably until a substantial flood event occurs. Monitoring will aid in any remedial actions, if necessary, and will improve similar future project designs.

CONCLUSIONS: According to the sponsors of this project, this demonstration of bioengineering treatments along with some structures has been tremendous for the Carson River Watershed. It has brought landowners and federal, state, and local government agencies together.

The project should be valuable to those considering future bank stabilization and restoration projects on the Carson River and other similar rivers in semi-arid and arid areas. Any applicability to other areas, however, should be conditional on a thorough site evaluation, i.e., hydrology, hydraulics and geomorphology, soil conditions, available and suitable native plants, and wildlife. Costs of the

project are very site-specific and are good general sources of information, but will vary with project location, access, contractors available, material availability, etc.

This hands-on demonstration project achieved good cooperation among various parties, including those in both the private and public sectors. The project was a great vehicle to convince others of the utility of new ideas that have not been attempted in the area and resulted in making the permitting process easier. Consequently, the project will facilitate future bioengineering projects of this type in the area

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> *www.wes.army.mil/el/wrap/*
> *www.wes.army.mil/el/elpubs/wqtncont.html*

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APPENDIX A – CROSS-SECTIONAL SURVEYS OF STREAM CHANNEL

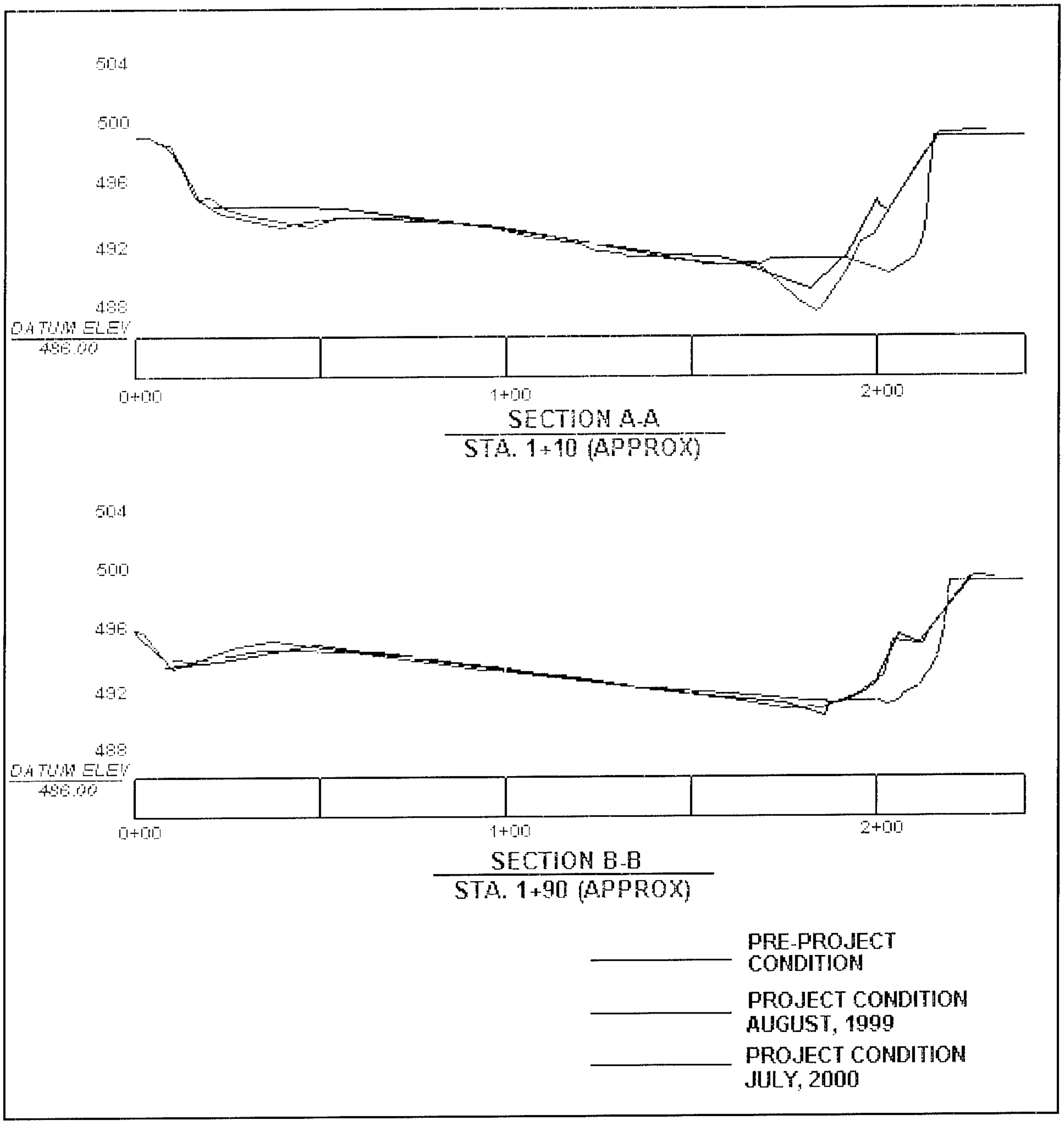

Figure A-1. A-A and B-B cross sections as though looking upstream. Note how thalweg has shifted to the left and sediment has accumulated on the right bank, the eroded bank of the bendway

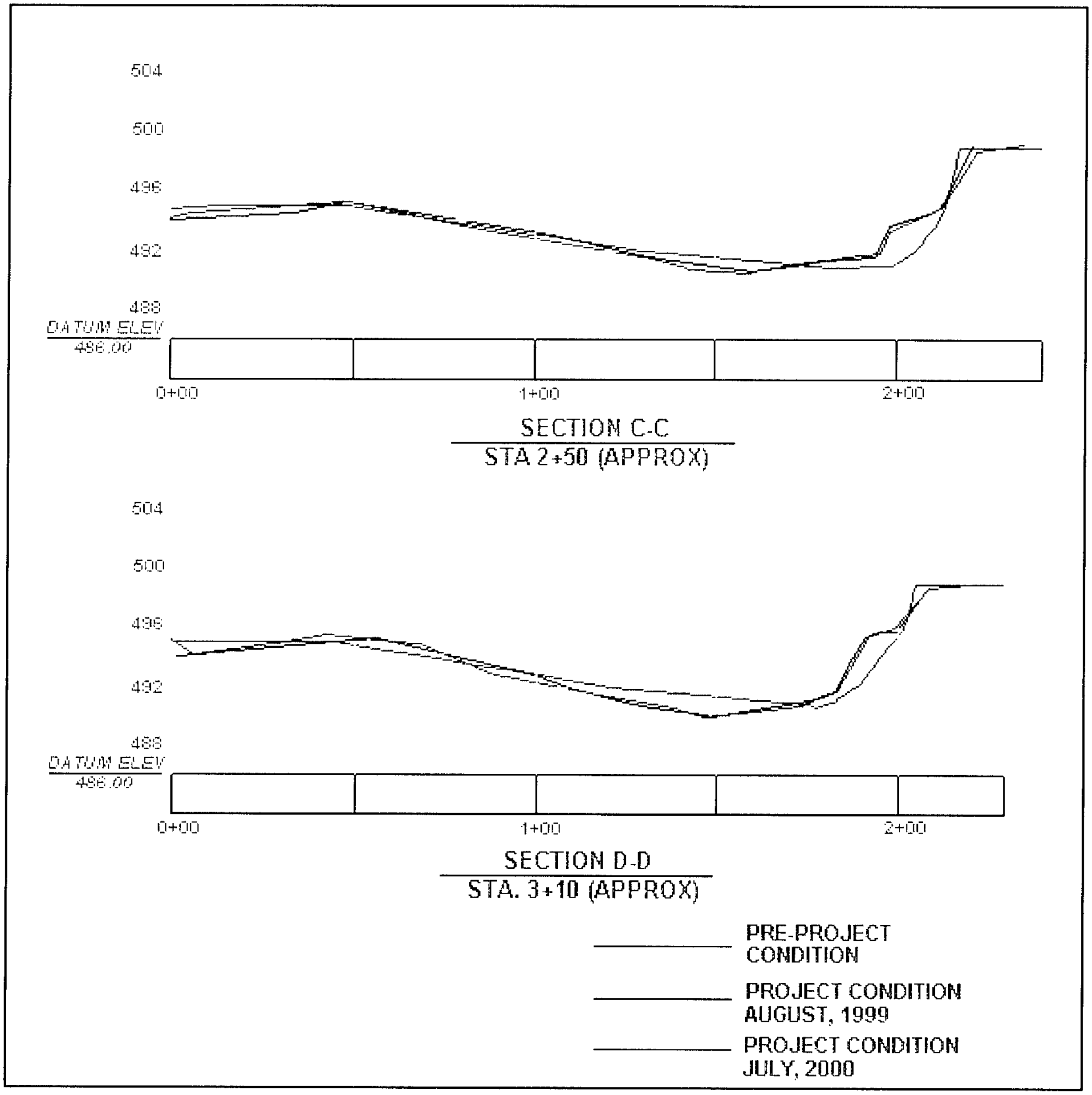

Figure A-2. Cross sections C-C and D-D as though looking upstream. Again, note how thalweg has shifted to the left and sediment has accumulated on the right bank

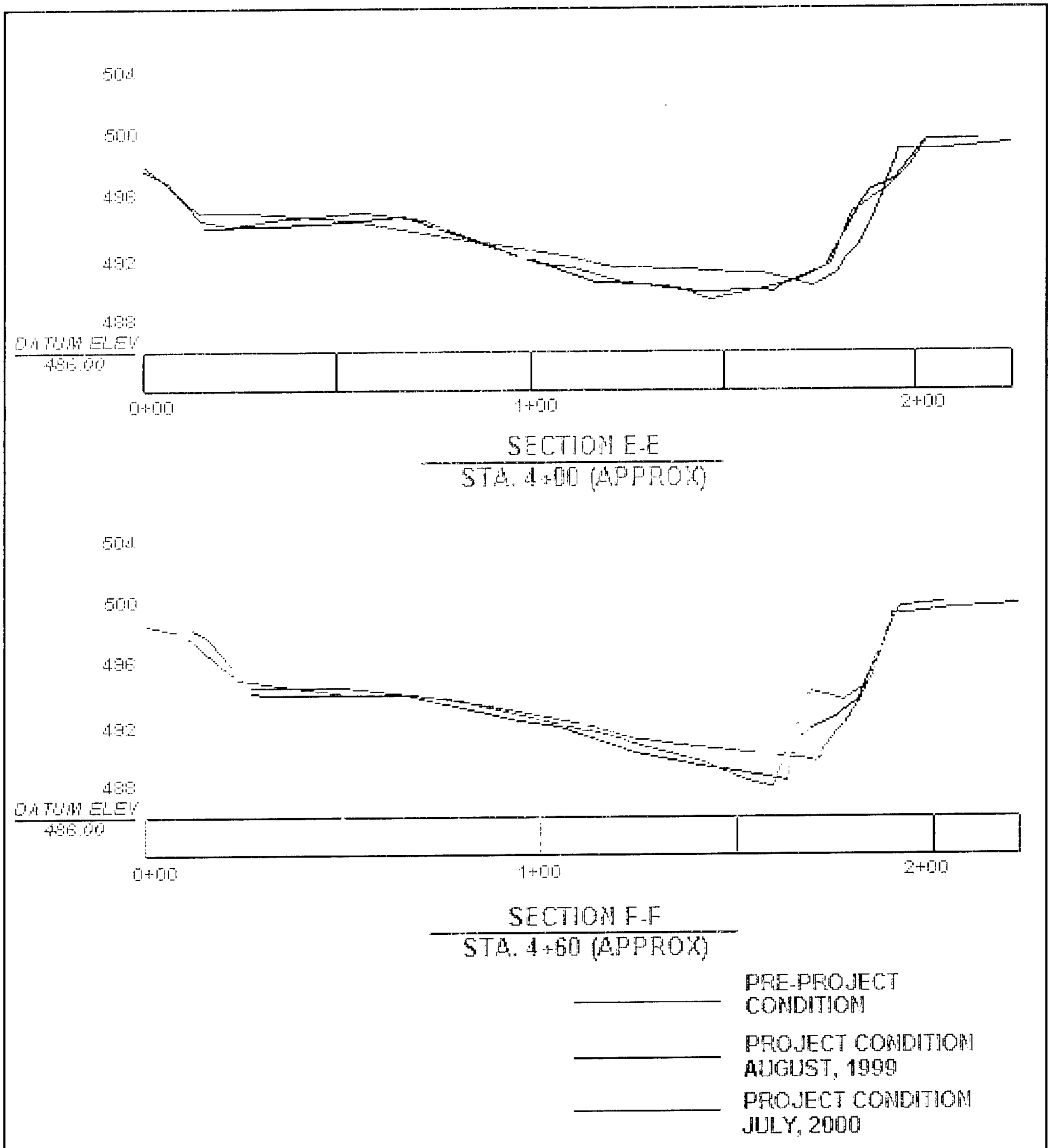

Figure A-3. Cross sections E-E and F-F as though looking upstream. Again, thalweg has shifted to the left

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